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INVESTIGATION ON DENSIFICATION BEHAVIOUR AND MECHANICAL PROPERTIES OF SINTERED HOT FORGED AISI 8720 PM STEELS

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ABSTRACT

Present experimental work has been evaluated the densification behaviour and mechanical properties of sintered hot forged AISI 8720 PM Steels by elemental powder through Powder Metallurgy techniques. Three aspect ratios were selected namely 0.55, 0.92 and 1.28 were prepared from Fe-0.20% C-0.28%Si-0.80%Mn-0.50%Cr-0.25%Mo-0.55%Ni powder blends using suitable die, punch and bottom insert on 1.0 MN capacity U.T.M in the pressure range of 480 ± 10 M Pa, 520 ±10 M Pa and 540 ± 10 M Pa respectively. The green Compacts were sintered at 1120 $\pm 10^0$ C for a period of 120 minutes under the protective ceramic coating. Sintered compacts were axially hot upset forged to different height strains with hydraulic screw press. The forged steels were heat treated in five different methods. The investigation on densification behaviour and Mechanical properties were studied with the calculated parameters. The sintered forged AISI 8720 steels show the existence of third and second order polynomial densification w.r.t height strain, bulging ratio, diameter strain, relative density and poisson's ratio. The lower aspect ratio 0.55 densified better than other aspect ratio performs. Sintered forged homogenised heat treatment samples shows better mechanical properties then sintered forged heat treated samples. Microstructure of the forged steels exhibited the presence of alloy carbides in ferrite matrix with the traces of martensite needles and bainite, pearlite grains. Fractography reveals mixed mode of fracture.

KEYWORDS: Hot Forging, Densification, Diameter Strain, Height Strain, Poisson's Ratio

INTRODUCTION

Powder metallurgy is an innovative art and scientific method of producing fine metal powder and objects finished or semi- finished from individual, homogeneously blended or alloyed metal powders with or without the inclusion of non – metallic constituents. Powder metallurgy techniques were applied for the production of electric contact materials, self-lubricating bearing, metal filters and structural parts. [1]. P/M technology enhances the accuracy rate and it plays a vital role in almost all automobile components. It is worth to quote that an average American Motor Car company employs up to around one hundred parts per one thousand parts, while in U.K. Motor Industry on an average uses forty eight P/M parts per one thousand [1]. In the automotive industry self-lubrication bearings, gears, cams, clutches, crank shafts, connecting rod and breaks can be produced from the P/M route. These parts are mostly made from low alloy steels. Uneven distribution of porosities in PM parts gives detrimental effect to their mechanical properties. [11]. Powder metallurgy techniques are applied in the production of electric contact materials consisting of tungsten as a hard refractory metal and either copper or silver. Copper graphite brushes are developed for electric motors and dynamos through PM techniques. Development in P/M are driving new innovation in the field of automotive transmission and valve trains (i.e., innovation of forward clutch hub employed in a continuously variable transmission (CVT), a torque transmission parts etc. Production of parts by P/M methods owes its strong position to economic considerations. By the process of die compaction and sintering, parts of intricate shape and with close dimensional tolerances can be produced which require no or a minimum of machining after sintering. PM technology is to enhance the properties of sintered powder material involves deformation process and another method could be liquid phase sintering or infiltration to attain high-density parts. P/M route basically has two processes. The primary P/M process includes powder production, powder blending, powder characterization, compaction and sintering. The pores in sintered P/M parts act as crack initiators during the application of these components in service and the crack initiation and its propagation would depend on the applied load and, therefore, in order to achieve full density, the pore closures become imperative [5]. Compaction is the step in which the blended powders are pressed into shapes in dies (Green Compact). The purposes of compaction are to obtain the required shape, density and particle to particle contact and to make the part sufficiently strong to be further processed. Forged P/M parts for mass produced structural parts are developed because of performance requirements that exceeded the strength levels of conventionally pressed and sintered P/M parts. Applications of

P/M forged parts have been increasing due to the economic advantages of P/M process and the availability of pre alloyed powders.[5]. A number of different parts are attempted for P/M forging, however, not all of these parts is successful because of either economic or technical reasons. Critical literature survey indicated that in order to fabricate high density P/M parts from sintered preforms, it is essential to adopt hard forging techniques using different shaped dies. The basic approach in any forming operation on sintered P/M parts is to enhance its density as close to theoretical as possible. This in turn would provide products possessing much improved mechanical properties. It has been well established that in no metal forming operation, the deformation strictly homogeneous and therefore pore closure mechanism would also be never homogeneous. The pores situated along the surfaces of the preform will never be able to close down either on account of predominance of tensile forces at the free surfaces or by hydrostatic forces at the die confinement. Hence, the existence of the particulate structure would be prevalent at the contact surfaces of the component with that of the die and punch [6]. Present investigation aims to evaluate the densification mechanism and mechanical properties of sintered forged AISI 8720 steels through PM route.

EXPERIMENTAL DETAILS

The materials required to carry out the present experiment are iron powder, graphite, nickel, chromium, manganese, molybdenum. Iron and all alloy powders of -180µm and 32 µm were obtained from standard metal powder companies. The chemical purity of all powders was found. The basic characterizations of iron and alloy powders were done. The characteristic features of iron powder and Fe-0.20% C-0.28%Si-0.80%Mn-0.50%Cr-0.25%Mo-0.55%Ni blends were carried out. The powder mixture were taken in a separate steel pots and tightened rigidly then the pot mill and allowed to operate for 36 hours to get homogeneous powder blend. Molybdenum di sulphide is needed as a lubricant during compacting. Suitable die, punch and butt are required for compacting the metal powders. After compaction Sintering was carried out in an electric muffle furnace for a period of 120 minutes at $1120^0 \pm 10^0$C and the samples were hot upset forged to different height strains and the large preforms were forged to square cross-section bars. The forged samples were heat treated in five different heat treatments such as Sintered forged oil quenching (SFOQ), sintered forged homogenous oil quenching(SFHOQ), sintered forged homogenous water quenching(SFHWQ), sintered forged homogenous furnace cooling(SFHFC) and sintered forged homogenous air cooling(SFHAC). These bar samples were machined for tensile testing. After machining, initial measurements were taken according to the requirement. The forged height strain and contact diameter values were measured for all upset forged samples. Measurements have been carried out to calculate deformation, height strain and diameter strain. The density also measured using Archimedean principle. The tensile specimens prepared from the square cross-section bars were tested under on micro tensile machine. Initial gauge length and diameter has been measure before testing. Final gauge length and diameter has been measured after testing by combining the two fractured parts. Fracture load and maximum load has been noted down from which the ultimate tensile strength, yield strength and percentage elongation including hardness were calculated. The sintered forged steels also have undergone Micro-structural properties and SEM analysis.

RESULTS AND DISCUSSIONS

The densification behaviour have been investigated with the relationship between fractional theoretical density, diameter strain vs height strain, bulging ratio vs fractional theoretical density and fractional theoretical density vs poisons ratio for AISI 8720 PM steel composition. Mechanical properties were evaluated and hardness value also identified. Micro structures of all five different heat treatments were identified.

Table 1: Coefficients of Third Order Polynomial of the Form: $(P_f/P_{th}) = A_1\varepsilon_h^3 + A_2\varepsilon_h^2 + A_3\varepsilon_h + A_4$; $E_h = \mathrm{Ln}\,(H_0/H_f)$

Aspect Ratio	A_1	A_2	A_3	A_4	R^2
0.55	0.191	-0.46	0.397	0.860	0.999
0.92	0.085	-0.261	0.96	0.86	0.999
1.28	0.030	-0.140	0.221	0.859	0.999

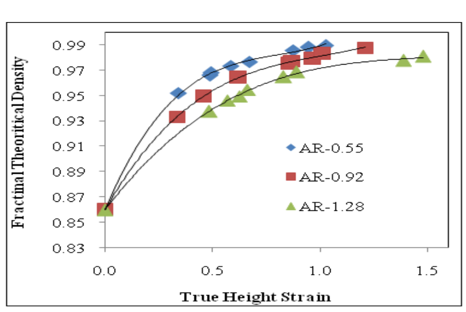

Figure 1: **True Height Strain vs Fractional Theoretical Density for AISI 8720 PM Steels**

Figure 1 has been drawn between fractional theoretical density and height strain for AISI 8720 PM steel compositions. It is observed that the technical analysis of these plots indicated that they conformed to a third order polynomial equations of the given form: $(\rho_f/\rho_{th})= a_1\varepsilon_h^3+a_2\varepsilon_h^2+a_3\varepsilon_h+a_4, \varepsilon_h=\ln(H_0/H_f)$; where '$a_1$', '$a_2$', '$a_3$', '$a_4$' are empirically determined constants. The 0.55 aspect ratio curve shows much higher densification then 0.92 aspect ratio performs densified middle level and 1.28 aspect ratio preform densified lower level. The values of regression coefficient 'R^2' in each case was found to be close to unity and, hence, the best fit curves. These empirical constants values have been tabulated in table-1.

Table 2: Coefficients of Third Order Polynomial of the Form: $\nu_p = b_1\varepsilon_h^3+ b_2\varepsilon_h^2+ b_3\varepsilon_h+ b_4;\ \varepsilon_h =(\rho_f/\rho_{th})$

Aspect Ratio	B_1	B_2	B_3	B_4	R^2
0.55	-5079	14931	14621	4770	0.993
0.92	-501.4	1479	-1448	471.2	0.965
1.28	-2471	7171	-6929	2230	0.959

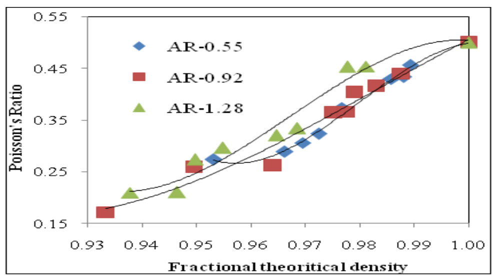

Figure 2: Fractional Theoretical Density vs Poisons Ratio for AISI 8720 PM Steels

Figure 2 drawn between the fractional theoretical density and poisons ratio. It is observed that all data points remained below the theoretical line irrespective of aspect ratio ascertaining the fact that the value of poisons ratio will always remain less than 0.50. The data points correspond to lower aspect ratio remain closer to theoretical line and the higher aspect ratio performs away from the theoretical line. The regression analysis of this curves has revealed that they followed a third order polynomial of the form: $\nu_p=b_1 (\rho_f/\rho_{th})^3+b_2(\rho_f/\rho_{th}))^2+b_3 (\rho_f/\rho_{th})+ b_4$ where 'b_1', 'b_2', 'b_3' and 'b_4' are empirical constants. The regression coefficients in all cases beyond 0.99 indicating the fact that the proposed relationship has been an accurate one The empirical constants values are tabulated in table.2

Table 3: Coefficients of Second Order Polynomial of the Form: $\mathrm{Ln}\ (D_c/D_0) = C_1\varepsilon_h^2+ C_2\varepsilon_h+ C_3; E_h = \mathrm{Ln}\ (H_c/H_0)$

Aspect Ratio	C_1	C_2	C_3	R^2
0.55	0.274	0.154	0.002	0.997
0.92	0.243	0.164	-0.007	0.996
1.28	0.232	0.123	-0.005	0.995

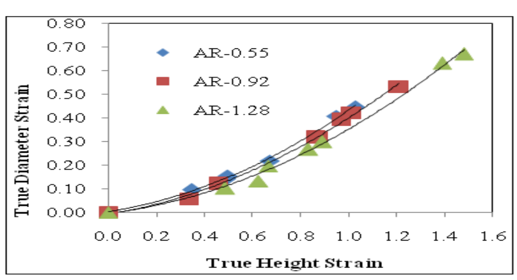

Figure 3: True Diameter Strain vs True Height Strain for AISI 8720 PM Steels

Figure 3 shows the relationship between diameter strain vs height strain. It is observed that almost all data points match fairly close with the straight-line equation. The lower aspect ratio preforms densified at a much faster pace compared to higher aspect ratio preforms. Numerical analysis of these curves indicates that theses data points corresponded to a second order polynomial of the form: $\ln (D_c/D_0) = c_1\varepsilon_h^2+c_2\varepsilon_h+c_3 = \ln (h_c/h_0)$ where 'c_1', 'c_2' and 'c_3' are Constants. The 'R^2' value found to be 0.99, which confirms a good curve fitting which matches to reliable empirical equation. The constant values are tabled in Table-3.

Table 4: Coefficients of Third Order Polynomial of the Form: $(P_f/P_{th}) = D_1\varepsilon_h^4+ D_2\varepsilon_h^3+ D_3\varepsilon_h^2+ D_4 E_{h+} D_5 ; E_h = \mathrm{Ln}\ (D_b/D_0)$

Aspect Ratio	D_1	D_2	D_3	D_4	R^2
0.55	-3.952	22.31	-47.12	44.18	0.998
0.92	-0.834	5.224	-12.28	12.91	0.998
1.28	-0.051	0.532	-1.894	2.807	0.998

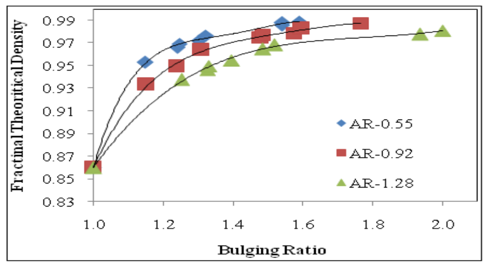

Figure 4: Fractional Theoretical Density vs Bulging Ratio for AISI 8720 PM Steels

Figure 4 shows the relationship between fractional theortical density vs bulging ratio. It is revealed that all data points fairly close with the theoretical density. Lower aspect ratio perform with respect to bulging will show more densification whereas higher aspect ratio performs shows lower densification. Technical analysis of the curves indicates the third order polynomial distribution. The regression coefficients value found to be 0.99 which indicates uniform curve fitting. The empirical constants are tabulated in table-4.

All the mechanical properties including tensile strength, yield strength, percentage elongation and percentage area reduction were calculated for the different heat treatments such as SFOQ, SFHOQ, SFHWQ, SFHAC and SFHFC. Mechanical properties of the systems investigated and are listed in Table 5

Table 5: Mechanical Properties of Upset Forged Square Cross-Section Bars of AISI 8720 PM Steels

Heat Treatment Conditions	Yield Strength (Mpa)	Tensile Strength (Mpa)	% Elongation	Hardness (HRC)
SFOQ	350	662	6.2	32
SFHOQ	492	785	10.2	37
SFHWQ	540	764	9.5	44
SFHAC	510	738	9.2	34
SFHFC	530	742	9.4	36

Table 5 indicates that the sintered forged homogenised samples of AISI 8720 PM steels shows better tensile strength and yield strength then forged condition sample. Sintered forged homogenous water quenching (SFHWQ) heat treated samples shows increased yield and the tensile strengths but has substantial change in the percentage elongation and area reduction. This establishes that though there is an increase in strength values, but, there is a little change in percentage of elongation and the percentage of area reduction, i.e., in ductility. Hardness values are high in the case of sintered homogenised heat treated samples and homogenised water quenched samples shows better hardness value. Hardness values for 8720 steels produced through P/M route corresponding to various heat treatments and different height strains i.e. square cross sectional bars and flattened discs were measured using Rockwell Hardness Tester.

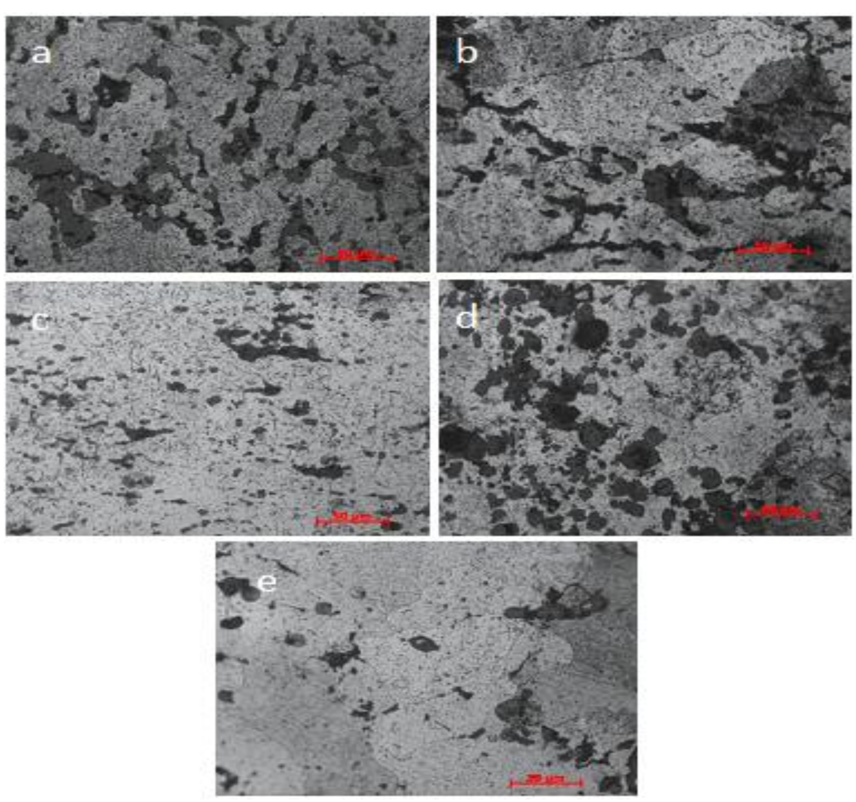

Figure 5: Microstructure of a) Sintered Forged Oil Quenching (SFOQ) Condition, b) Sintered Forged Homogenized Oil Quenching (SFHOQ), c) Sintered Forged Homogenized Water Quenching (SFHWQ), d) Sintered Forged Homogenized Furnace Cooling (SFHFC) e) Sintered Forged Homogenized Air Cooling (SFHAC)

Micro structural properties of sintered hot forged AISI 8720 PM Steel samples in figure 5 (a) SFOQ condition shows that the presence of alloy carbides in ferrite matrix. In figure 5 (b) SFHOQ condition shows that the presence of alloy carbides in ferrite with traces of martensite needles and fewer amounts of pearlite grains were seen In figure 5 (c) SFHWQ condition shows that the presence of alloy carbides in combined matrix of martentsite, bainite, pearlite and ferrite. In figure 5 (d) the SFHFC condition shows that the presence of alloy carbides in ferrite matrix very less amount of pearlite grains were also observed. in figure 5(e) SFHAC condition shows that the presence of alloy carbides in ferrite matrix with traces of martensite needles. Fractography of the fractured surface for all the five different heat treatment condition has established a mixed mode of failure, i.e., partly brittle and partly ductile or in some cases mostly ductile and partly brittle.

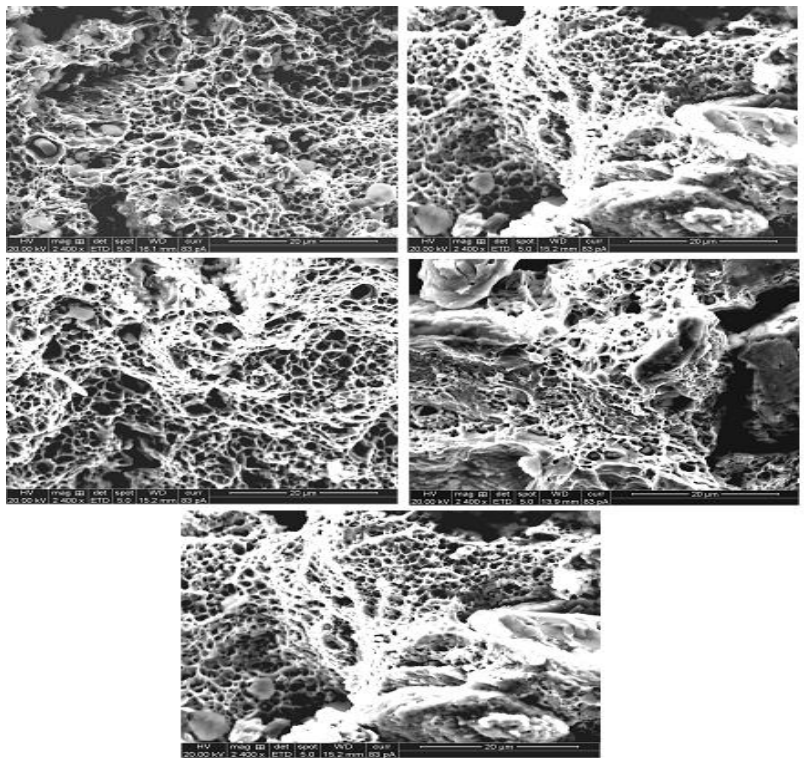

Figure 6: SEM Fractograph of a) Sintered Forged Oil Quenching (SFOQ) Condition b) Sintered Forged Homogenized Oil Quenching (SFHOQ), c) Sintered Forged Homogenized Water Quenching (SFHWQ) d) Sintered Forged Homogenized Furnace Cooling (SFHFC) e) Sintered Forged Homogenized Air Cooling (SFHAC)

CONCLUSIONS

Based on the above investigation and analysis of the experimental data with the calculated values the densification followed third order polynomial with respect to bulging ratio, fractional theoretical density and poisons ratio. The densification pattern with respect to true height strain and true diameter strain considered for AISI 8720 PM steels were found to follow a polynomial equation of second order. All the data points corresponding to the plots of true diameter and true height strains have been found below the theoretical line. The poisons ratio tends to approach a value 0.5. The lower preform aspect ratio densification is found higher than the higher aspect ratio performs. Mechanical properties such as yield strength, tensile strength are found to be good for sintered forged homogenised samples. The sintered forged homogenised water quenching (SFHWQ) heat treated samples shows increased yield strength and tensile strength but has substantial change in the percentage elongation and area reduction. Hardness values for AISI 8720 Steels are high in the case of sintered homogenised heat treated samples and homogenised water quenched samples shows better hardness value. Present investigation identifies the AISI 8720 P/M steels with higher densification and enhanced mechanical properties. Microproperty reveals that the presence of alloy carbides in the ferrite matrix with traces of martensite needles. In sintered forged homogenised furnace cooling (SFHFC) condition shows that the presences of alloy carbides in ferrite matrix with very less amount of pearlite grains were also observed. In sintered forged homogenised oil quenching (SFHOQ) condition shows that the presence of alloy carbides in ferrite with traces of martensite needles and fewer amounts of pearlite grains were seen. In sintered forged oil quenching (SFOQ) condition shows that the presence of alloy carbides in ferrite matrix and sintered forged homogenised water quenching (SFHWQ) condition shows that the presence of alloy carbides in combined matrix of matrentsite, bainite, pearlite and ferrite. Fractography of the fractured surface for all the five different heat treatment condition has established a mixed mode of failure, i.e., partly brittle and partly ductile or in some cases mostly ductile and partly brittle.

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